State of Practice for the Design of Bridge Fender Systems with Polymeric Materials

Andrew J. Bechtel
Assistant Professor
Department of Civil Engineering
Phone: 609-771-2475
E-mail: bechtela@tcnj.edu

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Impetus:

- NJDOT RFP-2014-15-02: *Fiberglass Composite Materials Specification Redevelopment*
- NJDOT Solicitation #108: *Bridge Engineering Services for Maintenance Bridge Fender Replacement*

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Impetus:

- Redevelopment of Section 916: Fiberglass Composite Materials into a performance based specification
  - One main goal was to understand how and where theses materials are used

- One of the main uses is in pile supported bridge fender systems

THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Fender Systems:

Prevent Damage to Bridge

- 35 people were killed when the Sunshine Skyway bridge was struck by a freighter and subsequently collapsed

Prevent Damage to Vessel

- The Cosco Busan dumbed 53,000 gallons of oil after striking a tower of the San Francisco-Oakland Bay Bridge

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Fender Systems from Composite Materials:

Corrosion of Steel and Concrete

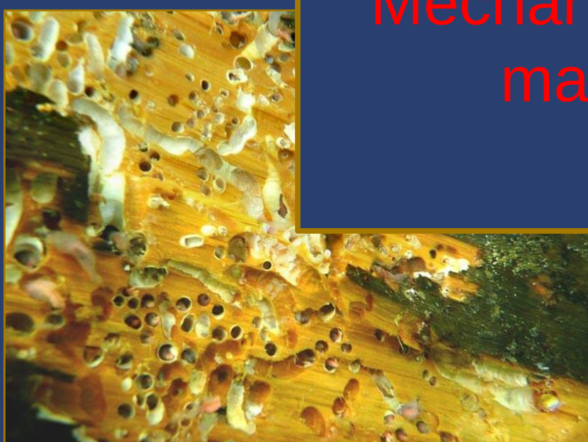
Marine Borers in Timber

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Fender Systems from Composite Materials:

Mechanical properties of composite materials can vary greatly!

ncrete



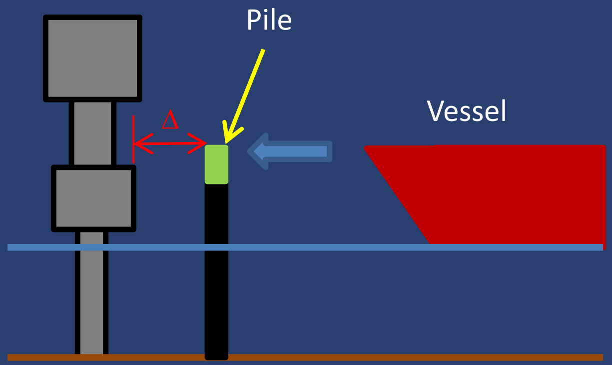
Marine Borers in Timber

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Fender Systems:

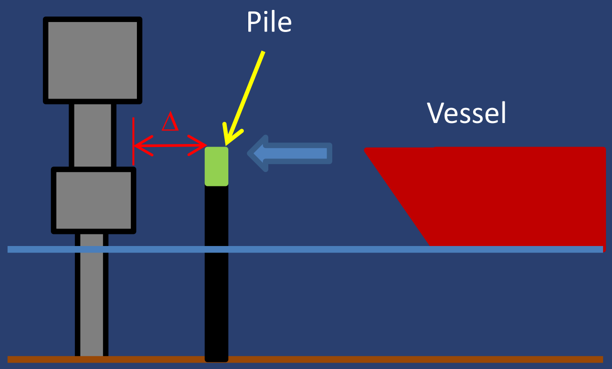
- Design of Fender Systems is an iterative process based on energy absorption (AASHTO: 3.14.15).
  - The kinetic energy of a moving vessel is dissipated by work done by flexure, shear, and torsion in the fender system

- The energy dissipated can be estimated from the area under the load deflection curve of the fender system



Fender Piles:

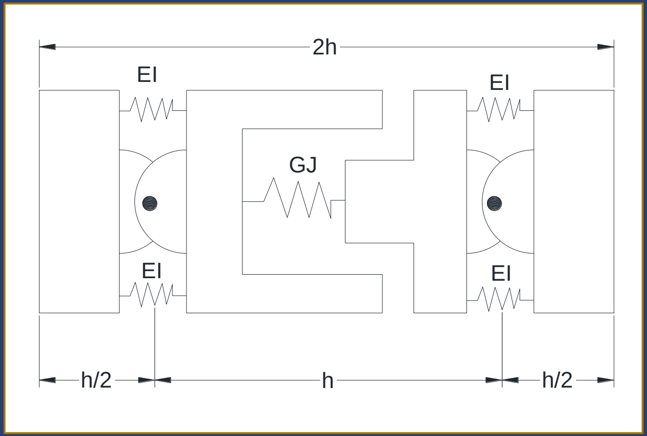
- Fender piles are designed for:
  - Lateral Resistance (AASHTO: 10.7.3.12)
  - Pile structural resistance (AASHTO: 10.7.3.13)
  - Drivability (AASHTO: 10.7.8)



THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Lateral Resistance (AASHTO 10.7.3.12)

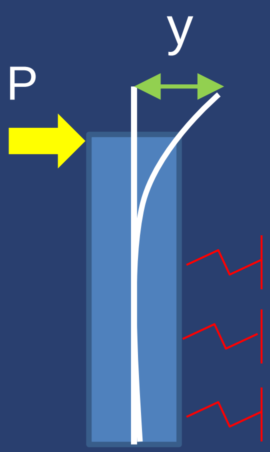
- Lateral resistance for a pile must be done using a method which accounts for load, geometry, and soil properties



$$EI\frac{d^4y}{dx^4} + P_x\frac{d^2y}{dx^2} + E_S y = 0$$

- Differential equation solved by Ensoft L-pile

- Discrete element formulation used in FB-Multipier by the Bridge Software Institute at the University of Florida



THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

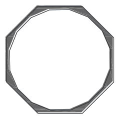
Pile Structural Resistance and Drivability

- Articles 10.7.3.13 and 10.7.8 of the AASHTO Bridge Design Specifications address pile structural resistance and drivability for timber, steel, concrete, and prestressed concrete piles, respectively

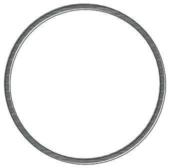
- Provisions associated with piles made of polymer composite materials have not yet been developed.

Polymer Materials:

Creative Pultrusion

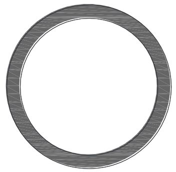


Series II CP076
203mm X 6.35 mm (8 in. X 0.25 in.)
E-glass reinforcement
Vinyl Ester Matrix



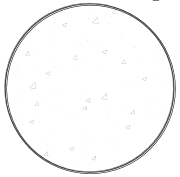
TU455
305mm X 9.52 mm (12 in. X 0.375 in.)
E-glass reinforcement Polyurethane Matrix

Harbor Technologies



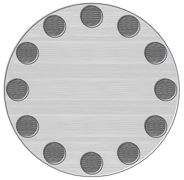
HarborPile
311mm (12.25 in.) O.D. 8 ply
E-glass reinforcement
Polyurethane or Vinyl Ester Matrix

Lancaster Composite

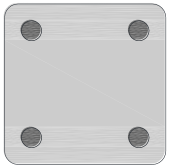


CP40
323 mm (12.7 in.) O.D.
E-glass reinforcement Epoxy or Polyester Matrix Concrete Infill

Bedford Technologies



SeaPile
330mm (13 in.) O.D.
Pile Material: High Density Polyethylene
13 FRP reinforcing bars
Bar Diameter 41 mm (1.625 in.)
Bar: E-glass reinforcement
Bar: Polyester Matrix



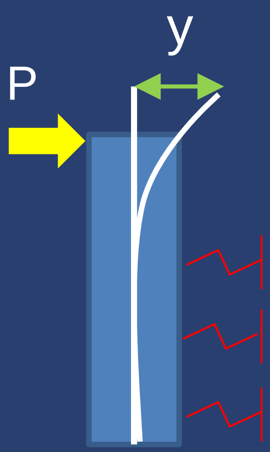
SeaTimber
305 mm X 305 mm (12 in. X 12 in.)
Pile Material: High Density Polyethylene 4 FRP reinforcing bars Bar Diameter 38 mm (1.5 in.) Bar: E-glass reinforcement Bar: Polyester Matrix

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Analysis of Polymer Fender Piles:

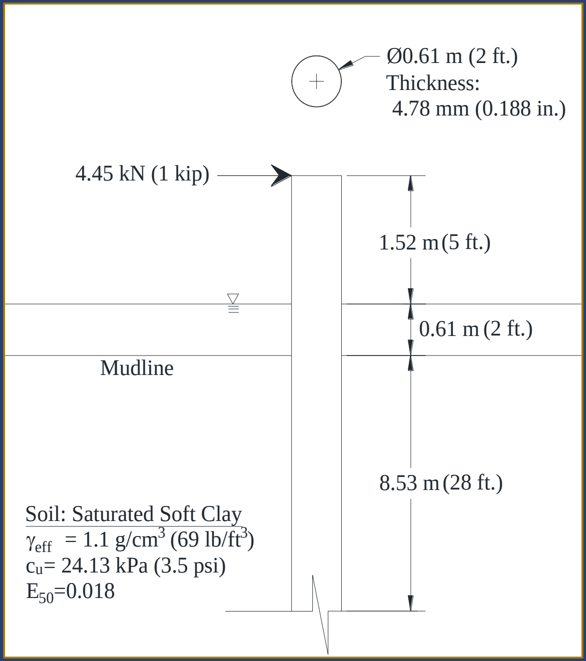
- Proper analysis of polymer composite fender systems must account for the inherent anisotropic and viscoelastic properties of the material

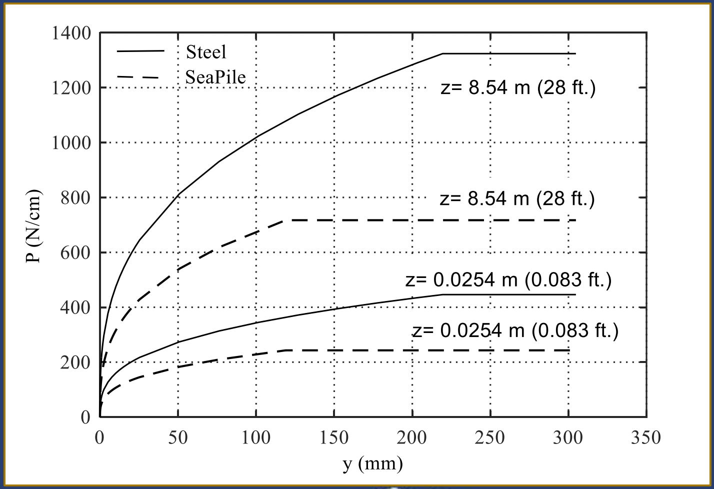
- When performing the P-y analysis, the shear deformation of the pile cannot be ignored.



Analysis of Polymer Fender Piles:

- To evaluate the significance of shear deformation on lateral deflection, P-y analyses were performed to compare a steel pipe pile to a SeaPile ® using a general FEA software
  - Pile discretized into 84 elements
  - Static nonlinear analysis performed

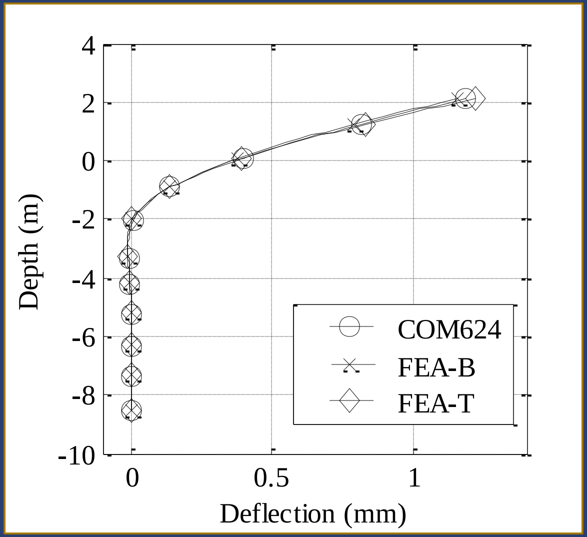


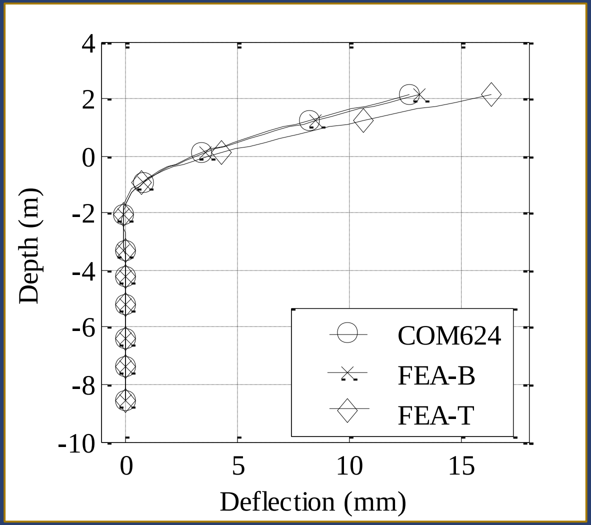


THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Analysis of Polymer Fender Piles:

Analysis	Steel Pipe Pile	SeaPile®
COM624	1.19 mm (0.0467 in.)	12.7 mm (0.500 in.)
FEA-B	1.16 mm (0.0455 in.)	13.1 mm (0.516 in.)
FEA-T	1.22 mm (0.0481 in.)	16.4 mm (0.644 in.)

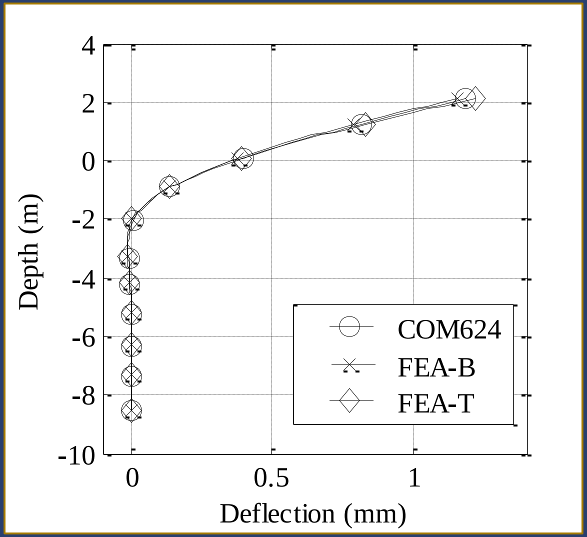


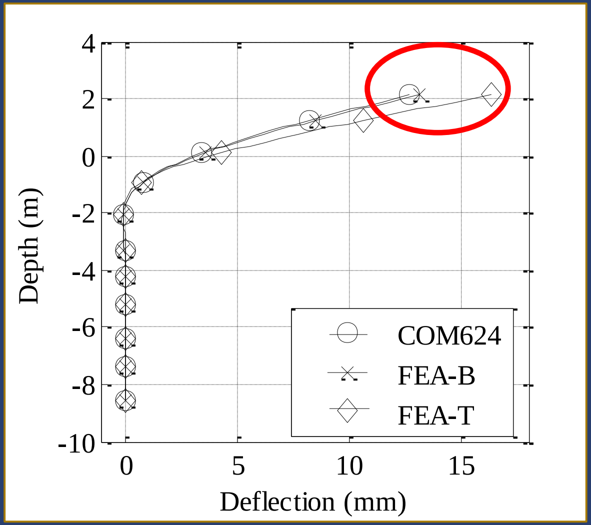


THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Analysis of Polymer Fender Piles:

Analysis	Steel Pipe Pile	SeaPile®
COM624	1.19 mm (0.0467 in.)	12.7 mm (0.500 in.)
FEA-B	1.16 mm (0.0455 in.)	13.1 mm (0.516 in.)
FEA-T	1.22 mm (0.0481 in.)	16.4 mm (0.644 in.)



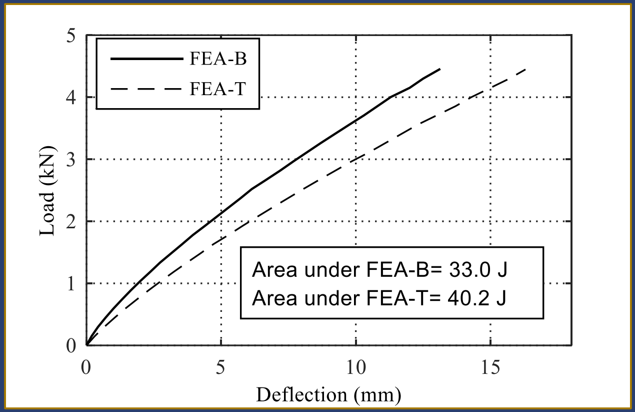


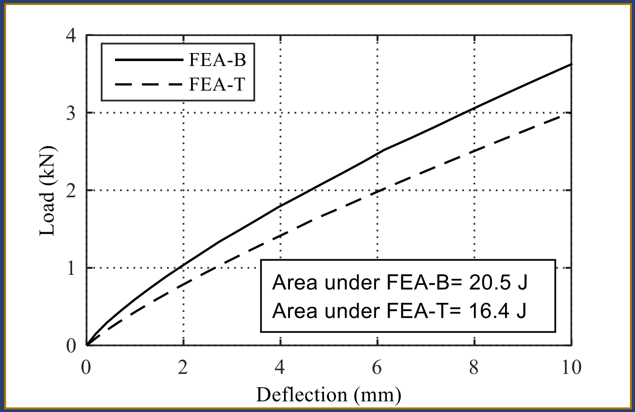
25% Increase

THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Analysis of Polymer Fender Piles:

- Depending on the limiting factor of the design, neglecting shear deformation can lead to unconservative estimates of the amount of energy absorbed



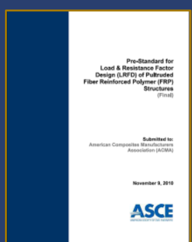


TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

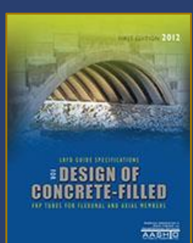
Strength Limit State:

- The strength of polymer composite piles can theoretically be estimated from existing guidelines and standards

ASTM D7258-14: *Standard Specification for Polymer Piles*



The ASCE Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures



The AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

ASTM D7258-14

- Claims applicability to all polymer composite pile systems
- The specification contains technical flaws that can jeopardize safety of some polymer composite pile systems
  - Nominal flexural stress is based on the assumption that each material will fail due to rupture at the extreme outer fiber.
    - Multiple other failure modes have been observed by multiple authors (Fam and Rizkalla, 2002; Polyzois et al., 1998; Mirmiran et al., 2000; and Zureick and Kim, 2002.)
  - Assumptions made in the development of stability factors are not applicable to piles made of anisotropic materials

THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

ASCE Prestandard

- Represents base technical background information upon which future standards will be created
- No guidelines are given for the determination of the flexural and shear strength of circular tubes
- The document gives explicit equations for the axial strength of circular pultruded tubes, but it provides no guidance as to how to determine moduli values for these tubes
- The structural performance is determined by laboratory testing approved by the Engineer of Record


Pre-Standard for
Load & Resistance Factor
Design (LRFD) of Pultruded
Fiber Reinforced Polymer (FRP)
Structures
(Final)

Submitted to:
American Composites Manufacturers
Association (ACMA)

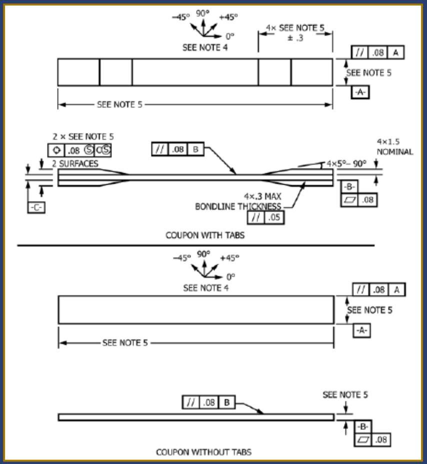
November 9, 2010

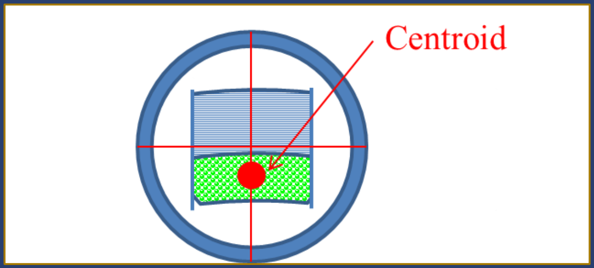
ASCE

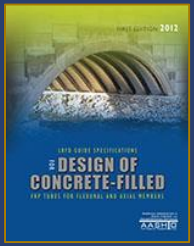
TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

AASHTO LRFD Guide:

- Determination of strength requires the axial strength of the FRP tube determined in accordance with ASTM D3039
- Coupons conforming with ASTM D3039 cannot be excised from circular tubes
  - The coupons must be rectangular in cross-section
  - The coupons must be balanced and symmetric







Fender Design with Polymer Materials:

- Design of fenders requires a reliable estimate of <u>shear rigidity</u>, <u>flexural rigidity</u>, and <u>ultimate strength</u>
  - Can be accomplished through testing pile products as simply supported beams under one and two point loads
  - With an adequate number of tests (Approx. 10) the characteristic values of the material properties can be determined using ASTM D7290 and used directly in design
- Shear deformations can be conservatively neglected when design is governed by load and larger deformations are acceptable
- When deflection is the limiting design factor, shear deformations must be accounted for

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

Thanks:

Mac Rashid
Fred Lovett
Angelo Mendola
Kimberly Sharp

Vedrana Krstic
Lauren Santullo
Alberto Torres

Abdul-Hamid Zureick

Aravinda Ramakrishna
Raymond Mankbadi

TRB
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Paper #17-01014

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Paper #17-01014

THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING

New tests:

TCNJ
THE COLLEGE OF NEW JERSEY
CIVIL ENGINEERING